Squeeze Casting Technology for Mg-Al-Ca Alloy Structural Parts

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Abstract: Four kinds of Mg-Al-Ca-Zn-Mn alloys with different Ca and Al mass ratios of 0.3, 0.6, 0.9, and 1.2 were studied. They are Mg-6.2Al-1.8Ca-0.7Zn-0.4Mn, Mg-5Al-3Ca-0.7Zn-0.4Mn, Mg-4.2Al-3.8Ca-0.7Zn-0.4Mn, and Mg-3.6Al-4.4Ca-0.7Zn-0.4Mn, respectively. By squeeze casting, alloys with high strength, good thermal conductivity, and acceptable heat resistance are obtained. The effect of the Ca/Al ratio on the microstructure and mechanical properties of the squeeze casting alloy was investigated. The Ca/Al ratio can be used to manipulate the mechanical properties of the alloy system, and the volume fraction, type, and morphology of the phases can also be controlled by the Ca/Al ratio. With the increase of the Ca/Al ratio, the yield strength increases, and the tensile strength decreases; the precipitated phase changes from Al_2Ca phase to $(Mg, Al)_2Ca$ phase and finally to Mg_2Ca phase.

Keywords: Mg-Al-Ca-Zn-Mn alloys; Squeeze casting; Organizational evolution; Mechanical property

1 Introduction

At present, most magnesium components are usually processed by high-pressure die casting (HPDC), and this process can produce magnesium alloy products with a certain complex structure at a low cost. However, in the production of complex thin-wall castings, it is easy to produce defects such as shrinkage holes and pores; as a result, the performance of magnesium alloys produced by die casting is low, and they often fail to meet the requirements of complex mechanical parts [1-3]. Therefore, the application of Mg-Al-Ca alloy in squeeze casting is studied in this paper. The squeeze casting process can produce castings with a certain complex structure and effectively eliminate defects such as porosity, shrinkage, and blowholes caused by casting during the solidification process [4]. The addition of Ca helps to improve thermal conductivity, refine the structure, and enhance the fluidity of the liquid metal, playing a beneficial role in both the casting and squeeze casting processes of mold filling and solidification [5]. In this study, C15-Al_2Ca, C36-$(Mg, Al)_2Ca$, and C14-Mg_2Ca phases in squeeze-cast Mg-Al-Ca alloys with four components were systematically studied. The four alloys showed different mechanical properties in the as-cast states, and the phenomenon was reasonably explained by a comprehensive analysis of their microstructures. Therefore, we systematically changed the Ca/Al ratio in Mg-Al-Ca alloys and studied the microstructure formation and mechanical properties of Mg-Al-Ca alloys in different squeeze-cast states.

2 Experimental procedure

Four kinds of Mg-Al-Ca-Zn-Mn alloys, with Ca and Al mass ratios of 0.3, 0.6, 0.9, and 1.2, were prepared. Their compositions are Mg-6.2Al-1.8Ca-0.7Zn-0.4Mn, Mg-5Al-3Ca-0.7Zn-0.4Mn, Mg-4.2Al-3.8Ca-0.7Zn-0.4Mn, and Mg-3.6Al-4.4Ca-0.7Zn-0.4Mn (they are expressed as C/A0.3, C/A0.6, C/A0.9, and C/A1.2, respectively).The alloys were fabricated in an electric-resistant furnace under an argon atmosphere by melting high purity Mg, Al, Zn, Mn, and Mg-30Ca intermediate alloys at 750℃ for 30 min. Magnesium alloy partition casting was produced by a SHP34-500A multifunctional liquid forming machine. The detailed parameters used in this study are as follows: pouring temperature, ~750℃; punch pressure, 125 MPa; punch speed, 0.63 m/s; mold holding time, ~55 s. Through scanning electron microscope (SEM) tests, we observe the analysis of the sample's microstructure and phase distribution. Through point-scan energy spectrum analysis, we examine the element distribution in the sample's microstructure to determine the composition of the phases.

3 Result and discussion

The SEM images of the four alloys in their cast states are shown in Fig. 1. EDS analysis was performed for different microstructure components at the points marked by characters in Fig. 1 (b, d, f, and h). EDS analysis shows that the main intermetallic phase in C/A0.3 alloy is $Mg_{17}Al_{12}$ and Al_2Ca; the main intermetallic phase in C/A0.6 alloy is Al_2Ca and $(Mg,Al)_2Ca$; the main intermetallic phase in C/A0.9 alloy is $(Mg,Al)_2Ca$; and the main intermetallic phase in C/A1.2 alloy is $(Mg,Al)_2Ca$ and Mg_2Ca.

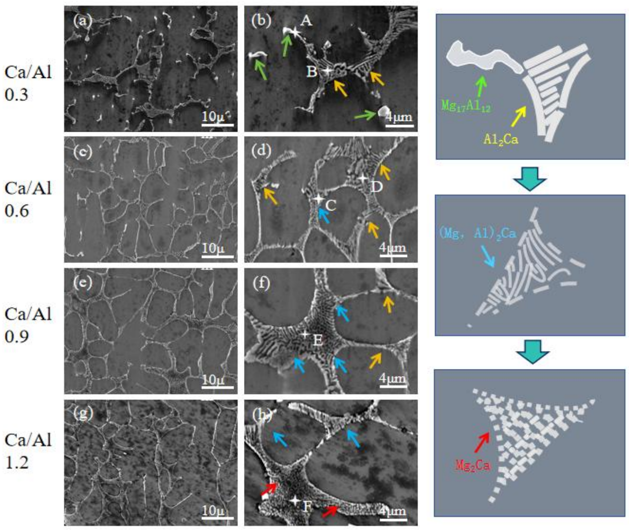

Figure 1. SEM images of as-cast alloys containing different Ca/Al ratios and a schematic diagram of the second phase changes, in which the green arrow marks the $Mg_{17}Al_{12}$ phase, the yellow arrow marks the Al_2Ca phase, the blue arrow marks the $(Mg,Al)_2Ca$ phase, and the red arrow marks the Mg_2Ca phase.

As the Ca/Al ratio increases, the YS increases, and the elongation decreases. Alloy C/A0.3 has a tensile strength of 152 MPa and 4.1% uniform elongation at room temperature, while alloy C/A1.2 shows a tensile strength of 134 MPa and 1.3% uniform elongation at room temperature. Alloys C/A0.6 and C/A0.9 exhibit intermediate YS, UTS, and UE values between alloys C/A0.3 and C/A1.2; alloy C/A0.6 has a tensile strength of 147 MPa and 3% uniform elongation.

4 Conclusion

(1) The Ca/Al ratio is an effective tool for controlling the type of second phase in Mg-Al-Ca alloys: from Al_2Ca and $(Mg,Al)_2Ca$ Laves phase at low Ca/Al ratios to $(Mg,Al)_2Ca$ and Mg_2Ca Laves phase at high Ca/Al ratios.

(2) As the Ca/Al ratio increases, the volume fraction of the second phase increases, along with their morphological changes: from a disconnected network of coarse laminae (Ca/Al=0.3) to an interconnected skeleton network of fine particles (Ca/Al=1.2).

(3) The second phase is the key factor affecting the strength of the alloy. The hardness, elastic modulus, and yield strength of the alloy increase with the increase of the volume fraction of the second phase, but the elongation and tensile strength decrease with the increase of the Ca/Al ratio.

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